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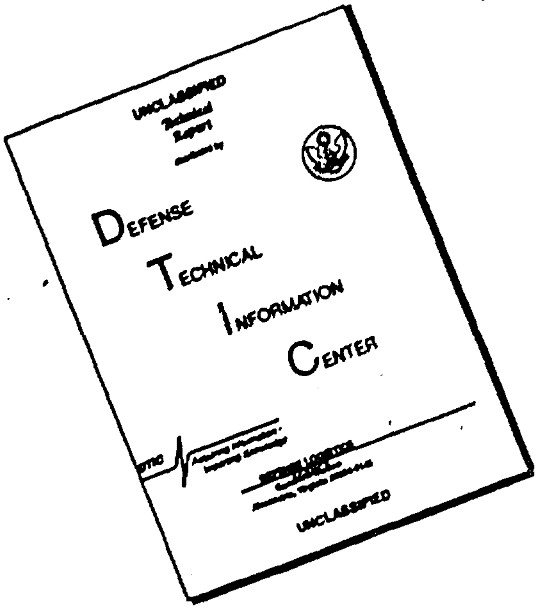

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~~Technical Report: NAVTRADEVCEN~~ 323-2

EXPERIMENTAL STUDY OF THE NATURAL PILOT FLIGHT PROFICIENCY EVALUATION MODEL

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ABSTRACT

This experiment investigated two major hypotheses generated by the Natural Pilot Model for Flight Proficiency Evaluation. These specify that human adaptability and economy of effort as understood in the context of servo-mechanism theory are important parameters of flying proficiency, and serve to differentiate proficient ("natural") from poor ("mechanical") operators. Adaptability was studied by systematically varying the controlled-element dynamics (control-display relationships); economy of effort, by varying the percent of time during which information was displayed (target intermittency). For all experimental conditions, the proficient trackers retained superiority over the poor ones. For intermittency conditions, performance decrement was the same for proficient and poor trackers. For the condition of changing control-display dynamics, one of the three measures of system performance showed less variation and less decrement for the proficient than for the poor trackers. Conventional tracking practice did not improve performance as measured by the adaptation and economy of effort criteria.

This study lends support to the basic hypotheses and therefore raises hope that this approach, which would obviate many of the criticisms of conventional proficiency measurement, is sound. However it also reveals difficulties in obtaining a cogent test of a model that attempts to combine servo-mechanism, perceptual-motor learning, and psychometric concepts.

F O R E W O R D

The measurement of pilot proficiency either in the OFT or the actual aircraft has been beset by a multitude of theoretical and practical difficulties. This is due to many factors, but especially to rater unreliability, task variations, differences between simulated and real flight situations, and gaps in the understanding of the basic nature of the flying task.

A new approach was taken in our studies at the Franklin Institute. Instead of specifying and describing the correct ways of performing a representative series of maneuvers, and then determining appropriate tolerances, the research aimed at evolving a generalized method that could be applied to any maneuver, and that would be valid regardless of aircraft type or the level of experience of the pilot; and regardless of whether measurement took place in the simulator or the aircraft.

During Phase I of this program (TR NAVTRADEVCEN 323-1), the ability of test pilots to evaluate the handling qualities of new aircraft, and the ability of LSO's (landing signal officers) to judge the correctness of pilot-aircraft performance were interpreted from the servo-mechanism viewpoint of skill-development. This led to the "natural pilot" model which hypothesized that the most efficient way to evaluate flight-control skills would be in terms of the pilot-aircraft system's consistency of performance despite vicissitudes of flight or mission; and in terms of the economy of effort which characterized the pilot's performance.

The first of these variables or factors is related to the pilot's adaptability, which is considered the human's most essential and unique contribution to the man-machine system; the second rests on the fact that highly-skilled performance is characterized by conservation or economy of effort ("least effort") and the need for less redundancy of information to accomplish its goal.

Phase II, the present study, constitutes an experimental test of both hypotheses. A compensatory-type tracking apparatus was used to obtain normative data of the stability of human performance during changes in control-display dynamics, and during forced economy of effort. The latter condition was elicited by systematically curtailing the percent of time that information was displayed to the operator while tracking.

The data showed a considerable relationship between generalized tracking ability and each of the two hypothesized factors of adaptability and economy of effort. The data also showed that the two hypothesized factors are independent; and that ordinary training, i.e., training not predicated on the special need for adaptability and economy of effort, was not successful in improving performance on these factors.

The findings substantiate the hypotheses. However, because of the difficulties encountered in testing our hypotheses, and in merging servo-mechanism, psycho-motor, and tests-and-measurement concepts--more research, especially with pilots of differing ability, must still be conducted.

If such experiments further confirm these and corollary hypotheses, the program should lead to more efficient performance measurement in a wide variety of aviation and space tasks. It would also make it easier to plan for performance evaluation in future man-machine systems for which no present criteria exist. Finally, it would have important implications for training, because training, or at least a good portion of it, could then be directed to the very heart of the skill, and thus lead to greater generality of transfer of training.

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BRIEF OF STUDY

The Phase I study of pilot proficiency (Krendel and Bloom, 1963) resulted in the specification of aspects of behavior unique to the pilot in a manned aircraft system. Rational comparisons of systems with both skilled and unskilled operators suggested that consistency of system performance despite changes in aircraft or pilot characteristics reflects human operator proficiency. Overall system stability appeared to be dependent upon two characteristics of the human operator: "adaptability" and "conservation of effort". These concepts imply that relatively invariant system performance results from adaptable operator performance and that the proficient operator performs under a minimum energy mode of operation.

This report describes a series of laboratory investigations intended to evaluate "adaptability" and "conservation of effort" as parameters of tracking performance. The purpose of these studies was to evaluate against criteria of system performance (a) ability of the human operator to adapt to changes in controlled element dynamics, (b) ability of the human operator to perform under different rates of target intermittency, and (c) the effects of tracking training upon these abilities.

Twenty-four Ss of known levels of tracking proficiency and experience were required to perform a compensatory tracking task first under conditions of changing controlled element dynamics and then under conditions of intermittent target presentation.

The effects of systematic changes in controlled element dynamics and target (or display) intermittency upon operator performance were measured and analyzed in a variety of ways. In all cases where stable measures were obtained, the proficient trackers retained their superiority over the poor ones. In the case of one measure, the proficient trackers suffered less decrement in performance as a result of changing dynamics than did the poor trackers, but in all other measures, the decrements due to changing dynamics or intermittency were the same for the proficient and the poor trackers. Additional training had no effect upon performance under any of the experimental conditions. The results support the hypothesis that "adaptability" and "conservation of effort" are important parameters of system performance in that the proficient operator exhibits adaptive behavior and economy of effort to a greater degree than the non-proficient operator. The results also show that these two measures are not correlated and therefore tap independent aspects of proficiency.

It must be emphasized that this was the first step in the measurement of adaptability and economy of effort as understood within the context of servomechanism theory, and that more refined ways of obtaining these criteria, both in pure tracking type tasks, and in tasks with simulated aircraft instruments must be developed and validated on pilots of known caliber before the practical role of these concepts can be fully evaluated.

INTRODUCTION

Background.

This program is concerned with the development and measurement of flying skills. In particular, we are concerned with perceptual motor skills rather than the various procedural and judgmental skills which a Naval Aviator must possess. It is the first experimental outgrowth of USNTDC Contract No. N 61339-323, Phase I, Study of Computer for Trainee Performance Evaluation. The Phase I study is summarized in Technical Report: NAVTRADEVCEN 323-1, The Natural Pilot Model for Flight Proficiency Evaluation (Krendel and Bloom, 1963). The Phase I program exhaustively examined the history and results of the various subjective and objective methods for measuring and improving piloting skills. In general, the results of the various sophisticated psychological examinations of the training process did not produce useful insights into the dynamics of the behavior patterns which characterize the piloting of an aircraft.

Areas peripheral to training, however, bring out the following salient reference points for our development. First, the day-to-day effectiveness of the Landing Signal Officer in making his split-second evaluations of piloting performance, which he bases on a complex of subjective factors associated with each pilot, makes it clear that subjective evaluations by skilled and insightful observers have a great deal of operational meaning. Second, the engineering applications of test-pilot opinion rankings of aircraft handling qualities to aircraft design further serves to validate the effectiveness of the judgments made by skilled observers in a flight task. Third, there exists a well-developed theoretical, and experimentally verified, correlation between the effective dynamics of the aircraft under evaluation and the expert pilot's judgments of handling qualities. Fourth, there is a large and detailed body of knowledge relating a servomechanism description of the closed loop control behavior of the pilot to the effective dynamics of the vehicle which he is flying.

The skeleton of the approach can now be seen. Subjective evaluations of piloting ability are both valid and valuable, but can we extract a measurable characteristic of piloting behavior which correlates with the subjective evaluation and which is susceptible to improvement by specific training techniques? By analogy with handling qualities theory, this characteristic should be the description of what the pilot has to do in a servomechanisms sense. In other words, what type of control device must the pilot be in order to fly at given levels of skill?

Let us examine motor skills, first intuitively, and then in fine grain in a servomechanism context. Skilled behavior is characterized first and foremost by its regularity - it is a process which is stable in the statistical sense. The execution of a well-timed lunge or parry in fencing, catching a fly ball, or a near-perfect carrier landing, are not rare events when performed by a skilled man. They are representative samples of his performance repertory. Stability of this sort, or as Krendel and Bloom denoted it, consistency of performance, to be useful, must be maintained over time. As time passes, however, the problem may change. Wind gusts may displace the fly ball, the aircraft may be damaged in combat, or the man himself may change through fatigue or injury. The skilled man must adapt his control behavior to both these external or internal changes in dynamics. Also, his performance must be relatively stable in time, even if the operator must engage in additional tasks that might suddenly be required; hence, some sort of least effort principle of control behavior must obtain for skilled behavior. Intuitively, the skilled performer makes the task look effortless, graceful, and easy. The human servomechanism then must be characterized by:

1. Adaptability - the ability to generate adaptive behavior as a function of the changing dynamic requirements.

2. Economy of effort - the ability to use energy resources efficiently so that motions are not wasted and performance can be sustained.

The problem now becomes one of identifying and selecting effective measures of adaptability and of economy of effort and then correlating these measures with levels of skill.

Approach.

In this study we measure adaptability and economy of effort by inference only. The reason is that direct measurement of either human dynamics or human metabolic activity involves equipment beyond the scope of this program. Inferential measurements suffer from a certain lack of resolution; however, they have the advantage of being simple and easily obtained under many experimental conditions. The assessment of motor skill provides somewhat of a problem, for the skills in which we are interested in the case of Naval pilots are those which distinguish the "natural" from the "mechanical" pilot. These are the skills which are difficult to acquire and also to evaluate by conventional atomistic methods, and are the ones that play a vital role in differentiating between highly successful and poorer pilots. We do not know to what extent they are related to the so-called innate skills that aptitude tests for pilot selection tend to measure, and to what extent they are incidentally acquired in the course of flying. But, based on the work of the first phase of this program, the hypothesis is put forth that the effective measurement of such skills will get at the very heart of flying proficiency and will have greater practicality and relevancy because, among other reasons, it provides a global, rather than atomistic measurement.

The experimental program which this report describes is a trial examination of the criteria suggested in the Phase I report. The subjects were college students participating in a tracking task which bore an intuitively satisfying, and logically defensible, relationship with flight control tasks. Subjects were separated into two distinct groups -- proficient trackers and poor trackers -- on the basis of the skills which they brought to the task from the very beginning. These groups were exposed to the task and the two inferentially measured criteria of skill were obtained.

The first part of the major experiment consisted of presenting a subject with a set of changing controlled element dynamics in which he was required to respond in such a manner as to maintain an acceptable level of system performance. His ability to maintain consistent system performance under conditions of changing controlled element dynamics was taken as a measure of his ability to adapt. The second part of the major experiment focused on economy of effort. This was studied in terms of time needed to maintain system performance, a decreased time requirement to perform a task being considered characteristic of decreased pilot effort. The proficient operator should be capable of recognizing and taking advantage of the coherence and predictability of stimuli and of the relationship between his control and the stimuli, and thus he should require less time and less information to perform his task than the non-proficient pilot. By systematically varying the time during which the operator is permitted to view the stimuli, it is possible to evaluate this effect in relation to a measure of system performance. In order to obtain insight into the effect of training on performance, an additional concern under both experimental situations was the effect upon system performance of amount of previous practice on the task. The measured index of performance was RMS error. This conventional measure of error is particularly appropriate in this case because it emphasizes large departures in performance from a base level.

EXPERIMENTAL PROGRAM

The experimental program consisted of two preliminary studies which established levels of difficulty of controlled element dynamics, and useful rates of target intermittency; and of two main experiments directed toward the establishment of "adaptability" and "time in control" criteria (Experiments I and II).

Apparatus.

The apparatus used in the preliminary studies and the subsequent experiments was an analog computer compensatory tracking device (Figure 1). A schematic diagram of the apparatus is given on page 30 of the Appendix. The target consisted of a spot of light, approximately 1 mm. in diameter, displayed on the face of an oscilloscope. A set of cross hairs was used to indicate the null (zero error) position. Target motion was horizontal and was furnished by a random noise generator (Barnes, 1955). The noise source was set to produce a target motion of bandwidth two radians/second. The tracking control device, a rotary control, consisted of a freely turning knob and a pointer mounted on a disk (Figure 1). A clockwise rotation of the pointer moved the target from left to right. The absolute value of the error, and the integrated error squared were recorded by means of Esterline Angus recorders.

S sat approximately 28 inches from the face of the scope which was normal to his line of vision. The tracking control device was mounted on an arm rest which inclined at an angle of 20 degrees. S sat in a conventional classroom chair modified to accomodate the control device.

Preliminary Study 1

Subjects.

Six male members of the staff of the Franklin Institute Laboratories served as Ss. Each subject had about 30 minutes of tracking experience in a previous exploratory study which had been designed to select, from among many possibilities, the most promising sets of control dynamics for this study.

Procedure.

Ss were required to perform a compensatory tracking task under two forms of controlled element dynamics: $Y_c = K_c$ and $Y_c = K_c/s$ where $K_c = 2, 10, 15$ and $1/s$, $5/s$, $15/s$, and $30/s$ respectively.[1] Ss were briefly instructed in the operation of the device. Each S tracked under all conditions, the total tracking time for each condition being three minutes. For each S, the order of presentation of the tasks was randomized with a three minute rest interval between each task.

Results

The score for each condition was taken as the RMS error in inches on the face of the scope over the last minute of tracking. The means and standard

[1] See glossary (p 36-38) for explanation of controlled element dynamics.

Figure 1. The Tracking Control Device

deviations of these data are presented in Table 1.

Table 1

Means and Standard Deviations of RMS Error for Controlled Element Dynamics

Controlled Element Dynamics (Y_c)	M	SD
2	0.25	0.07
10	0.23	0.03
15	0.26	0.04
1/s	0.39	0.06
5/s	0.44	0.03
15/s	0.48	0.04
30/s	0.44	0.04

The analysis of variance of the data is summarized in Table 2. The *F* of 67.00 for controlled element dynamics was significant at less than the .01 level.

Table 2

Analysis of Variance for Controlled Element Dynamics

Source	*df*	*MS*	*F*
Dynamics (D)	6	0.067	67.00**
Subjects (S)	5	0.002	2.00
D x S	30	0.001	

**Significant at less than .01 level

Duncan Multiple Range Tests (Duncan, 1955) of the difference between the means were performed to determine which of these control dynamics differed significantly from each other in RMS error. The means of three control dynamics, Y_c = 10, Y_c = 1/s, and Y_c = 15/s were found to be significantly different from each other at the .01 level. Thus, three difficulty levels, easy, intermediate, and difficult were established for use in the major experiment.

Preliminary Study 2

Subjects.

Six male members of the staff of the Franklin Institute Laboratories served as Ss. These subjects, just as the Ss in the first preliminary study, had participated in an exploratory study to select promising sets of control dynamics, and thus had about 30 minutes of tracking experience. Ss had been assigned to one or the other of the two preliminary studies on a random basis.

Procedure.

Ss were required to perform the compensatory tracking task under eight conditions of target intermittency. A blanking generator described in the appendix provided an intermittent target signal. Target on time was maintained at 0.25 seconds as suggested by Lindquist and Gross (1958) and off time was varied between 0.25 and 4.75 seconds (Table 3). The fraction of "off time" per cycle was defined as

$$= \frac{\text{Time off (sec.)}}{\text{Time off (sec.)} + .25\text{ (sec.)}}$$

Controlled element dynamics were maintained at the intermediate level of difficulty, $Y_c = 1/s$, established in the first preliminary study. After being instructed in the operation of the apparatus, Ss tracked for three minutes under each condition. The order of presentation of the conditions was randomized with a three minute rest period between each.

Table 3

Conditions of Target Intermittency

Time On (sec.)	Time Off (sec.)	% of Total Time Off
0.25	4.75	95
0.25	2.25	90
0.25	1.42	85
0.25	1.00	80
0.25	0.58	70
0.25	0.38	60
0.25	0.25	50
1.00	0.00	0

Results

System performance was expressed as the RMS error in inches over the last minute of tracking. The mean RMS error in inches for each condition of intermittency is shown in Table 4. The means were compared in the Treatments x Subjects analysis of variance summarized in Table 5.

Table 4

Means and Standard Deviations of RMS Error for Intermittency

% of Time Off	M	SD
95	0.60	0.07
90	0.53	0.04
85	0.50	0.04
80	0.46	0.04
70	0.42	0.05
60	0.43	0.02
50	0.45	0.04
0	0.39	0.03

Table 5

Analysis of Variance for Target Intermittency

Source	df	MS	F
Intermittency (I)	7	0.026	13.00**
Subjects (S)	5	0.002	1.00
I x S	35	0.002	

**Significant at less than .01 level

The F of 13.00 for target intermittency rates was significant at less than the .01 level. Differences between the means were assessed by Duncan Multiple Range Tests (1955) in order to establish distinct levels of difficulty. The means for three levels of intermittency were found to be different from each other at well beyond the .01 level of statistical significance. These were the target-off times of 95%, 85%, and 60%, respectively, which later served as the difficult, intermediate, and easy intermittency tasks of the second major experiment.

The Major Experiment

Experiments I and II were conducted with the framework of a single experimental design. The purpose of these studies was to evaluate against criteria of system performance (a) ability of the human operator to adapt to changes in controlled element dynamics (Experiment I), (b) ability of the human operator to perform under different rates of target intermittency (Experiment II), and (c) the effects of amount of previous operator exposure to the task upon these criteria (Experiments I and II).

Table 6 summarizes the experimental design. Ss task consisted of compensatory tracking under conditions of: (a) shift in control sensitivity (Experiment I) and (b) intermittent target presentation (Experiment II). Prior to the experimental sessions, Ss were screened and divided into two groups, good trackers (proficient) and poor trackers (non-proficient), and were subjected to one of two levels of experience with the task.

The same Ss were used in each of two experimental periods. The experimental sessions occurred one week after the preliminary screening. Ss performed the tracking task under conditions of change in control sensitivity during the first period (Experiment I) and under conditions of target intermittency during the second period (Experiment II). Trial and sequence effects were controlled by presenting the tasks as prescribed by a 3 x 3 Latin square.

Method

Apparatus.

The apparatus was the same as used in the preliminary studies. (See pages 29-30 in the Appendix.) Changes in controlled element dynamics were accomplished by an automatic switching mechanism which changed amplifier gains and feedback at specified time intervals; target intermittency was achieved by a blocking oscillator and a pulse width control.

Subjects.

Thirty-six paid volunteer male undergraduate students from local universities served as Ss. None of the Ss had previous tracking experience. On the basis of preliminary screening, this group was reduced to 24 Ss.

Preliminary Session.

The proficiency of Ss as measured by RMS error over the last minute of tracking was assessed in a preliminary session during which they were engaged in three minutes of compensatory tracking. During this session, control sensitivity was at the intermediate level[1] $Y_c = 1/s$. On the basis of performance on this task, Ss were divided into two highly distinct groups, good

[1]Based on the first preliminary study.

Table 6

Experimental Design

Proficiency	Experience	Order	Experiment I Trial 1	Experiment I Trial 2	Experiment I Trial 3	Experiment II Trial 1	Experiment II Trial 2	Experiment II Trial 3	Subject
Good	Training	I	B**	C	A	F**	E	D	1
		II	A	B	C	D	F	E	2
		III	C	A	B	E	D	F	3
		I	B	C	A	F	E	D	4
		II	A	B	C	D	F	E	5
		III	C	A	B	E	D	F	6
	No Training	I	B	C	A	F	E	D	7
		II	A	B	C	D	F	E	8
		III	C	A	B	E	D	F	9
		I	B	C	A	F	E	D	10
		II	A	B	C	D	F	E	11
		III	C	A	B	E	D	F	12
Poor	Training	I	B	C	A	F	E	D	13
		II	A	B	C	D	F	E	14
		III	C	A	B	E	D	F	15
		I	B	C	A	F	E	D	16
		II	A	B	C	D	F	E	17
		III	C	A	B	E	D	F	18
	No Training	I	B	C	A	F	E	D	19
		II	A	B	C	D	F	E	20
		III	C	A	B	E	D	F	21
		I	B	C	A	F	E	D	22
		II	A	B	C	D	F	E	23
		III	C	A	B	E	D	F	24

**Latin letters A, B, and C = three levels of change in controlled element dynamics.
D, E, and F = three levels of intermittency.

trackers and poor trackers. The good trackers consisted of the 12 Ss with the lowest RMS error; the poor trackers consisted of the 12 Ss with the highest RMS error. The remaining Ss were dropped. The difference in mean RMS error between the two groups was significant at less than the .001 level ($t = 6.96$, $df = 22$).

Tracking Experience.

In order to introduce prior training as an independent variable, half the good trackers and half the poor trackers received an additional 12 minutes of experience with the compensatory tracking task before the experimental session. The remaining Ss received no additional experience. During this session, control sensitivity again was at the intermediate level of difficulty[1] $Y_c = 1/s$.

Experimental Session - Experiment I.

Experiment I dealt with adaptability, i.e., compensatory tracking under conditions of changing controlled element dynamics. There were three levels of change in dynamics, each constituting a tracking task lasting six minutes. Every level started with two minutes of tracking with $Y_c = 1/s$ and ended with two minutes of $Y_c = 1/s$, but the tracking during the third and fourth minute was performed under changed control sensitivity: $Y_c = 10$ for the first, $Y_c = 5/s$ for the second, and $Y_c = 15/s$ for the third level. The following tabulation summarizes these levels or tasks:

	First Two Minutes	Second Two Minutes	Third Two Minutes
1. level	$Y_c = 1/s$	$Y_c = 10$	$Y_c = 1/s$
2. level	$Y_c = 1/s$	$Y_c = 5/s$	$Y_c = 1/s$
3. level	$Y_c = 1/s$	$Y_c = 15/s$	$Y_c = 1/s$

Thus, at the end of the second minute, and at the end of the fourth minute a change of dynamics took place on each level. Since $Y_c = 10$ had been found in the preliminary study to be easy, $Y_c = 5/s$ intermediate, and $Y_c = 15/s$ difficult, the three levels afforded an opportunity to study the effect of the difficulty of the inserted task upon the subjects' reaction to the change.

The subjects were not informed that a change of dynamics (control-display relationships) would occur during this experiment.

Experimental Session - Experiment II.

The second experimental session occurred 30 minutes after the first. During this session, Ss were required to perform the compensatory tracking task under each of the three levels of target intermittency, easy, intermediate, and difficult, shown in Table 7. Controlled element dynamics was maintained at the intermediate level of difficulty, $Y_c = 1/s$. Prior to the experimental session, Ss were informed that the target would appear intermittently. They were permitted to observe the behavior of the target and to attempt to track under these conditions. The total tracking time under each

[1] Based on the first preliminary study.

condition was six minutes.

Table 7

Conditions of Target Intermittency

Time On (sec.)	Time Off (sec.)	% of Total Time Off	Level*
0.25	4.75	95	Difficult
0.25	1.42	85	Intermediate
0.25	0.38	60	Easy

*Based upon results from Experiment II

Results

Experiment I.

To assess the effect upon system performance of Ss response to changing controlled element dynamics, an error score and a time score were obtained at each level of change. The error score was taken as the difference between RMS error (in inches) measured over a half-minute interval before change in dynamics and the RMS error measured over a half-minute interval after change in dynamics. These constituted the intervals between 1.5 and 2 minutes, and between 4 and 4.5 minutes tracking for each of the three tasks or levels. Since, as was pointed out above (p 12), the first 2 minutes and the last 2 minutes of each of the 6-minute tracking tasks were performed at $Y_c = 1/s$, all scores are based on $Y_c = 1/s$ only. The time score was the time in seconds to **return to and maintain for 15 or more seconds an absolute error score equal to or less than a base line plus or minus one standard deviation. The base line was defined as the mean level of system performance (i.e., mean level of absolute value of the error) over the 30 seconds prior to the first change in dynamics. Measures were taken every 1.25 seconds.**

The means and standard deviations of the time and error scores are presented in Tables 8 and 9 respectively. The means of these measures were compared by a five classification replicated Latin square analysis of variance (Tables 10 and 11).

Analysis of variance (Table 10) with difference in RMS error before and after change of dynamics as the measure of system performance resulted in a F of 4.99 for proficiency significant at less than the .05 level. In general, the smallest differences in RMS error were obtained for those systems containing proficient trackers. Since most of the differences were in the direction of increased error, it can be concluded that the poor trackers revealed not only greater variability but a greater decrement as a result of change in dynamics than did the proficient trackers. The F's for experience and the Dynamics x Proficiency interaction were not significant. Nor were any of the remaining main effects or interactions significant. Thus we can conclude that the greater performance variability and decrement of the poorer

Table 8

Means and Standard Deviations of Time (in Seconds) to Achieve Base Line Under Conditions of Change in Controlled Element Dynamics[1]

Level of Change of Controlled Element Dynamics	Good Trackers				Poor Trackers			
	Training		No Training		Training		No Training	
	M	SD	M	SD	M	SD	M	SD
1	12.08	27.02	17.60	23.14	32.19	40.78	18.44	19.53
2	50.21	39.84	34.69	40.40	26.62	42.84	32.92	45.49
3	44.17	51.34	43.75	45.40	33.18	22.69	29.22	42.95

[1] **Based on original data. Means and standard deviations of the transformed scores appear in Table IA, Appendix, page 31.**

Table 9

Means and Standard Deviations of Difference in RMS Error
30 Seconds Before and After Change in Dynamics[1]

Level of Change of Controlled Element Dynamics	Good Trackers				Poor Trackers			
	Training		No Training		Training		No Training	
	M	SD	M	SD	M	SD	M	SD
1	0.15	0.05	0.17	0.09	0.23	0.08	0.20	0.04
2	0.17	0.05	0.17	0.03	0.16	0.08	0.24	0.07
3	0.17	0.04	0.06	0.03	0.18	0.01	0.19	0.08

[1]Based on original data. Means and standard deviations of the transformed scores appear in Table 2A, Appendix, page 32.

Table 10

Analysis of Variance for Controlled Element Dynamics:
Difference in RMS Error 30 Seconds Before and After Change in Dynamics [1)]

Source	df	MS	F
Between Subjects	23		
Proficiency (P)	1	0.000349	4.99*
Training (T)	1	0.000001	
Sequence (S)	2	0.000253	3.61
P x T	1	0.000085	1.21
P x S	2	0.000015	
T x S	2	0.000068	
P x T x S	2	0.000103	1.47
Error	12	0.000070	
Within Subjects	48		
Dynamics (D)	2	0.000078	2.05
Trials (Tr)	2	0.000093	2.45
D x P	2	0.000017	
D x T	2	0.000085	2.24
D x P x T	2	0.000081	2.13
Tr x P	2	0.000006	
Tr x T	2	0.000117	3.08
Tr x P x T	2	0.000037	
Error	32	0.000038	

*Significant at less than .05 level.
[1)] **Based on transformed data.**

Table 11

Analysis of Variance for Controlled Element Dynamics: Time to Return to Base Line[1)]

Source	df	MS	F
Between Subjects	23		
Proficiency (P)	1	0.0543	
Training (T)	1	0.0049	
Sequence (S)	2	0.4550	
P x T	1	0.4278	
P x S	2	0.5349	
T x S	2	2.0156	2.14
P x T x S	2	0.0441	
Error	12	0.9406	
Within Subjects	48		
Dynamics (D)	2	0.8287	
Trials (Tr)	2	0.9679	
D x P	2	1.5926	2.60
D x T	2	0.1325	
D x P x T	2	0.5219	
Tr x P	2	0.1750	
Tr x T	2	0.5454	
Tr x P x T	2	0.2235	
Error	32	0.6121	

[1)] **Based on transformed data.**

trackers was true regardless of level of change in dynamics or level of training.

To further assess the effect of changes in controlled element dynamics and operator proficiency upon system performance, the mean RMS error over all levels[1], for the 30 seconds prior to change, was compared with the mean RMS error over all levels[1] for the first 30 seconds after the second change (Y_c = 1/s in both cases). The means and standard deviations for each level of proficiency appear in Table 12. Analysis of variance[2] resulted in F's for proficiency and dynamics significant at less than the .01 level (Table 13). The Dynamics x Proficiency interaction was not significant. For both the proficient and non-proficient Ss, changing controlled element dynamics resulted in a decrement in system performance. The magnitude of the difference between the two groups for both the pre-change and post-change conditions remained relatively constant.

With the time score as the measure of system performance, none of F's resulting from analysis of variance were significant[3].

---

[1]Differences in RMS error at each level prior to pooling were not significant (see Appendix, p 34).

[2]The effects of training, trials, and sequence were assumed to be non-significant as in the previous analysis.

[3]The variances of these scores were very high, and the observed differences among the means were unrelated to any of the variables. To determine whether this was due only to details of measurements, the time score as measure of system performance was obtained in several other ways. In one of these, we measured time to return to, and maintain for 10 seconds an error score equal to or less than the subject's own (rather than mean) base line ± one sigma. None of these other methods of obtaining time scores yielded significantly different means, or smaller variances than the ones reported in our original measures.

While time to adjust to changing control dynamics seemed to be an important aspect of adaptability on theoretical grounds, it failed to stand up under this particular experimental test. It may be that other variables in the task masked its influence, and that measuring time-to-adjust in tasks with simulated aircraft instruments might have yielded a more stable measure of adaptability.

Table 12

Means and Standard Deviations of RMS Error
Before and After Change in Dynamics

Level of Change of Controlled Element Dynamics	Level of Proficiency			
	Proficient		Not Proficient	
	M	SD	M	SD
B[1]	0.31	0.05	0.40	0.06
A[2]	0.34	0.05	0.43	0.05

[1]Based on mean RMS error over all levels for the 30 seconds prior to change.

[2]Based on mean RMS error over all levels for the 30 seconds after change.

Table 13

Analysis of Variance for Dynamics

Source	df	MS	F
Between Subjects	23		
Proficiency (P)	1	0.0916	19.91**
Error	22	0.0046	
Within Subjects	24		
Dynamics (D)	1	0.0080	11.43**
P x D	1	0.0022	
Error	22	0.0007	

**Significant at less than .01 level

Experiment II.

For each level of intermittency, the RMS error in inches over the last two minutes of tracking was taken as the measure of system performance. The means and standard deviations of the original data appear in Table 14. Because of the presence of a large number of zero scores in the original data, it was advisable to transform the scores before carrying out the analysis of variance (Federer, 1955; Kempthorne, 1952). The details of the transformation and the transformed means and standard deviations appear in the Statistical Appendix. Comparison of the means of the transformed scores was accomplished by a five classification replicated Latin square analysis of variance (Table 15). The analysis resulted in an $\underline{F}$ of 134.91 for target intermittency which was significant at less than the .01 level. Increased rates of target intermittency were accompanied by increases in the magnitude of the RMS error. Differences between the three rates of intermittency were significant at the .01 level in Duncan Multiple Range Tests.

The $\underline{F}$ of 7.06 for proficiency was significant at less than the .025 level. Neither the main effects of training, sequences, or trials nor any of the interactions of these effects or of proficiency and training were significant.

The relationship between the means for proficiency and level of intermittency is presented in Figure 2. Also shown is the base point obtained in Experiment I, i.e., the mean RMS error over all levels of change in controlled element dynamics for the 30 seconds prior to change. Systems containing proficient $\underline{S}$s produced less RMS error than those with non-proficient $\underline{S}$s. This relationship remained constant for all levels of intermittency and was not affected by training. Ignoring the proficiency of the $\underline{S}$s, system performance was best with continuous target presentation and deteriorated progressively with target off-times of 60, 85, and 95 per cent.

Relationship Between the Measures.

A rank difference correlation between the RMS error scores for controlled element dynamics and the RMS error scores for intermittency resulted in a Spearman Rho of .38. The Rho failed to reach significance at the .05 level ($\underline{t}$ = 1.93, $\underline{df}$ = 22). A Rho of .39 was obtained between the RMS error score and the time score for controlled element dynamics. The $\underline{t}$ of 1.99 was not significant at the .05 level ($\underline{df}$ = 22). The small magnitude of the Rho's and their failure to reach significance indicates that there is little or no relationship between the measures.

Table 14

Means and Standard Deviations of RMS Error at Each Intermittency Level[1]

% of Total Time Off	Good Trackers				Poor Trackers			
	Training		No Training		Training		No Training	
	M	SD	M	SD	M	SD	M	SD
95	0.68	0.07	0.69	0.11	0.79	0.18	0.74	0.08
85	0.51	0.03	0.51	0.12	0.52	0.05	0.58	0.05
60	0.42	0.03	0.36	0.02	0.42	0.02	0.45	0.03

[1]Based on original data. Means and standard deviations of the transformed scores appear in Table 3A, Appendix, page 33.

Table 15

Analysis of Variance for Target Intermittency[1]

Source	df	MS	F
Between Subjects	23		
Proficiency (P)	1	0.01201	7.06*
Experience (E)	1	0.00002	
Sequence (S)	2	0.00007	
P x E	1	0.00070	
P x S	2	0.00235	1.38
E x S	2	0.00027	
P x E x S	2	0.00125	
Error	12	0.00170	
Within Subjects	48		
Intermittency (I)	2	0.13761	134.91**
Trials (Tr)	2	0.00074	
I x P	2	0.00024	
I x T	2	0.00116	1.14
I x P x E	2	0.00228	2.24
Tr x P	2	0.00159	1.56
Tr x E	2	0.00100	
Tr x P x E	2	0.00021	
Error	32	0.00102	

[1]Based on transformed data.

*Significant at less than .025 level.

**Significant at less than .01 level.

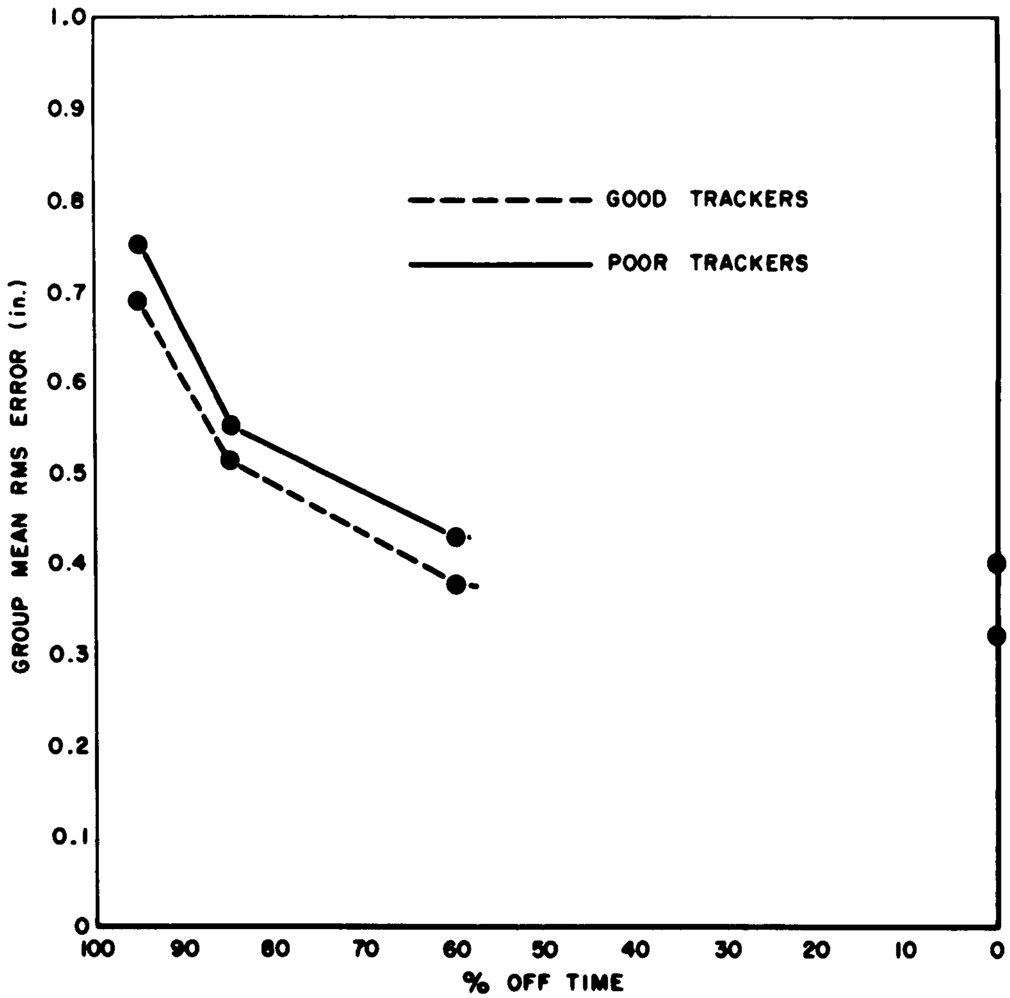

FIG. 2. GROUP MEAN RMS ERROR AT EACH LEVEL OF TARGET INTERMITTENCY FOR GOOD AND FOR POOR TRACKERS
(The Zero Off Time Record Comes From Experiment I)

General Discussion.

Systems containing proficient trackers displayed higher system performance under all conditions of changing controlled element dynamics and target intermittency. Considering ability to function under these conditions as criteria of adaptability and conservation of effort respectively, it was found that the proficient tracker (a) exhibits adaptive behavior to a greater degree than non-proficient trackers, and (b) exhibits a greater degree of conservation of effort. If one allows extrapolation from the known to the unknown "percentage off" times (Figure 2), one can argue that the poor operator group's performance with an uninterrupted display was equalled by that of the good pilot's with a 70 per cent off time. In other words, one might argue that good trackers do as well as poor trackers with only 30 per cent of the effort.

Another interpretation of the effect of intermittency is possible. Since a high level of vehicle control is possible under high levels of intermittency, it follows that the remaining signal contains enough information for such control. What is lost during the "off time" must therefore be mainly redundancy. When the residual information falls below some value, e.g., that information displayed at about 70 per cent off time, performance worsens rapidly. We conclude, therefore, that the difference in rate of error increment

$$\frac{\Delta \text{ error}}{\Delta \text{ intermittency}}$$

between good and poor trackers (Figure 2) is due in an important part to the efficiency of data processing (or, in other terms, to a tendency on the part of poor trackers to respond to irrelevant information which good trackers ignore). Another way of saying the same thing is that poor trackers have something like a built in source of noise so that the required redundancy for a given level of information transmission is greatly increased. This is not an unexpected finding and it finds strong support from various physiological investigations. First of all, it should be noted that no response of an organism ever occurs in isolation. There are always a number of simultaneous responses occurring. It is well known that one main difference between skilled and unskilled performance is the amount of tenseness which the trainee exhibits. Skilled performance is characterized by general relaxation. Only those muscle groups directly involved in the performance are active. But unskilled performance is different. Beginners are tense all over (literally). Unskilled trackers using (say) their right hands will show significant muscular action potentials in their left big toe. This tenseness is in general facilitory in the sense that it reduces reaction time, etc. But since inappropriate responses are facilitated as much or more than appropriate response, the net effect is a reduction in efficiency. These inappropriate responses are equivalent to noise in an information sense. Thus, we have a basis for the requirement of poor trackers for a greater degree of redundancy.

Use of the tracking task in the present investigation was based upon its importance as a component of the pilot's task and its general acceptance as a criterion of pilot performance. Changing controlled element dynamics were intended to simulate changes in aircraft dynamics during flight; intermittency of target simulated conditions during which attention might be diverted (e.g., during emergency, combat, or routine non-flight tasks). The relationship between ability to meet these two types of conditions and system consistency was demonstrated.

Although the present investigation demonstrates the consistency of our measures with tracking proficiency, their exact role in predicting differences in proficiency of experienced pilots and students at various levels of training needs to be established. Rank difference correlations between the RMS error measure of Ss performance under continuous tracking conditions[1] and the mean error scores for changing controlled element dynamics and intermittency resulted in Rhos of .48 (df = 22, t = 2.57) and .54 (df = 22, t = 3.01) respectively, significant at less than the .05 level. These relatively low correlations, when considered within the context of the theory and experiment of this program, suggest an important implication for the prediction of pilot performance: It may well be that adaptability and economy of effort test aspects of flight performance that conventional measures have never tapped. While only an experiment with pilots of exceptional, high, and average proficiency can determine the appropriate weights that should be assigned to these two measures, great care must be taken that the differentiation of criterion pilots be made on the basis of global types of measures (e.g., LSO opinion based on several carrier landings) rather than on the item-by-item evaluation of conventional measurement which might mask the role of "natural" pilot skills.

The lack of correlation between adaptability and conservation of effort, once these measures have been validated on pilot populations, will be an operational advantage. Because in any equation for the prediction of performance, predictors that have a correlation with that performance, but not with each other, account for a larger share of the predictive effort.

The extra tracking experience which half the proficient and half the poor subjects had received prior to the main experiment had no effect upon system performance. It is essential to note that what is called in this experiment "training" did not include tracking under conditions of changing dynamics or intermittent appearance of the target, but merely continuous tracking; and that none of the subjects received detailed instructions concerning the nature of tracking under changing or intermittent conditions. Failure to obtain improvements in adaptability or conservation of effort should therefore not be surprising. However, the operational situation parallels this, inasmuch as the major portion of training, both in simulators and in training aircraft, is more related to this study's continuous tracking than to changing dynamics or intermittency; thus, despite extensive training, the so-called "natural" pilot skills are probably not always acquired and some pilots become "overloaded" when an unusually high degree of adaptability and conservation of effort suddenly become essential to mission success.

Two major research issues will have to be resolved before direct application of this study's criteria can be made to fleet practice:

1. Adaptability and economy of effort can be measured by tracking tasks such as the ones used in this study, or by simulated aircraft instruments modified to permit systematic changes in control-display dynamics and intermittency. Which of these two means of measuring adaptability and economy of effort is the more efficient predictor of overall flying proficiency?

---

[1]Pre-shift base line of Experiment I.

2. What is the effect of extensive practice on tasks that measure our two criteria, upon subsequent flying performance?

It must be admitted that research to answer these questions is difficult and time-consuming because of the multitude and complexity of variables that are involved in motor-skill and transfer of training, many of which are still unexplored. But once the most efficient measures of our two criteria have been identified, great payoffs in pilot proficiency measurement and training will be possible.

REFERENCES

Barnes, G. H., A Four Channel Noise Source, USAF, WADC TR-55-194, 1955.

Duncan, D. B., "Multiple Range and Multiple F Tests", Biometrics, 1955, 11, 1-41.

Federer, W. G., Experimental Design, New York: MacMillan, 1955.

Kempthorne, O., The Design and Analysis of Experiments, New York: John Wiley and Sons, 1952.

Krendel, E. S. and Bloom, J. N., The Natural Pilot: A Criterion System for Flight Proficiency Evaluation, TR NAVTRADEVCEN 323-1, Port Washington, New York: U. S. Naval Training Device Center, 1963.

Lindquist, A. H. and Gross, R. L., Human Engineering Man-Machine Study of a Weapon System, Minneapolis-Honeywell Regulator Company, MHAer Report R-E06094, 1958.

APPENDIX

APPARATUS

The apparatus consisted of an analog computer and a tracking device composed of a manually operated rotary control and a display (Figure 1). A schematic diagram is given in Figure 3.

The tracking control arm activated transducers for electrical take-off to the system. The dotted lines enclose four alternative feedback connections. Since the feedback and input impedances were readily changeable, considerable flexibility was available. Selection of a particular network was switch controlled. A timing device permitted automatic switching of amplifier gains and feedback at uniform time intervals.

Target motion was furnished by a random noise generator (Barnes, 1955). A switch operated filter selected target motion band widths. The loop was completed by a summing amplifier and a display consisting of a standard laboratory oscilloscope.

The "blanking generator" consisted of a blocking oscillator of variable frequency (a Hewlett Packard Model 202A Low Frequency Function Generator was used for this purpose) and a pulse width control. Width control allowed adjustment of the on-off ratio.

Error voltage was fed through a squaring circuit and integrated (circuits not shown). Integrated error squared was recorded by means of Esterline Angus Recorders. Paper speed was set at twelve inches per minute.

With the exception of the display, tracking device, and variable frequency generator, the components were assembled in a single 19 inch rack.

Experiments I and II.

For both the time and the error scores, the means and the variances were proportional. The intermittency data contained a number of zero scores. It was therefore advisable to transform the data prior to the execution of the analysis of variance. The most appropriate transformation was found to be $\mathrm{Log}_{10} + 1$, for the time data, $\mathrm{Log}_{10}\, X + 5$, for the error data, and $\sqrt{X + .5}$ for the intermittency data (Federer, 1955; Kempthorne, 1952). The means and standard deviations of the transformed scores are presented in Tables 1A, 2A, and 3A. A replicated five classification Latin square analysis of variance was applied to the transformed scores of each measure (Tables 12, 13, and 15). The means and standard deviations of Tables 10, 11, and 14, are in terms of the original (non-transformed) measures.

Tables 4A and 6A present the means and standard deviations for each level of change in controlled element dynamics for the 30 seconds prior to change and the 30 seconds after change respectively. The analysis of variance for these means appear in Tables 5A and 7A.

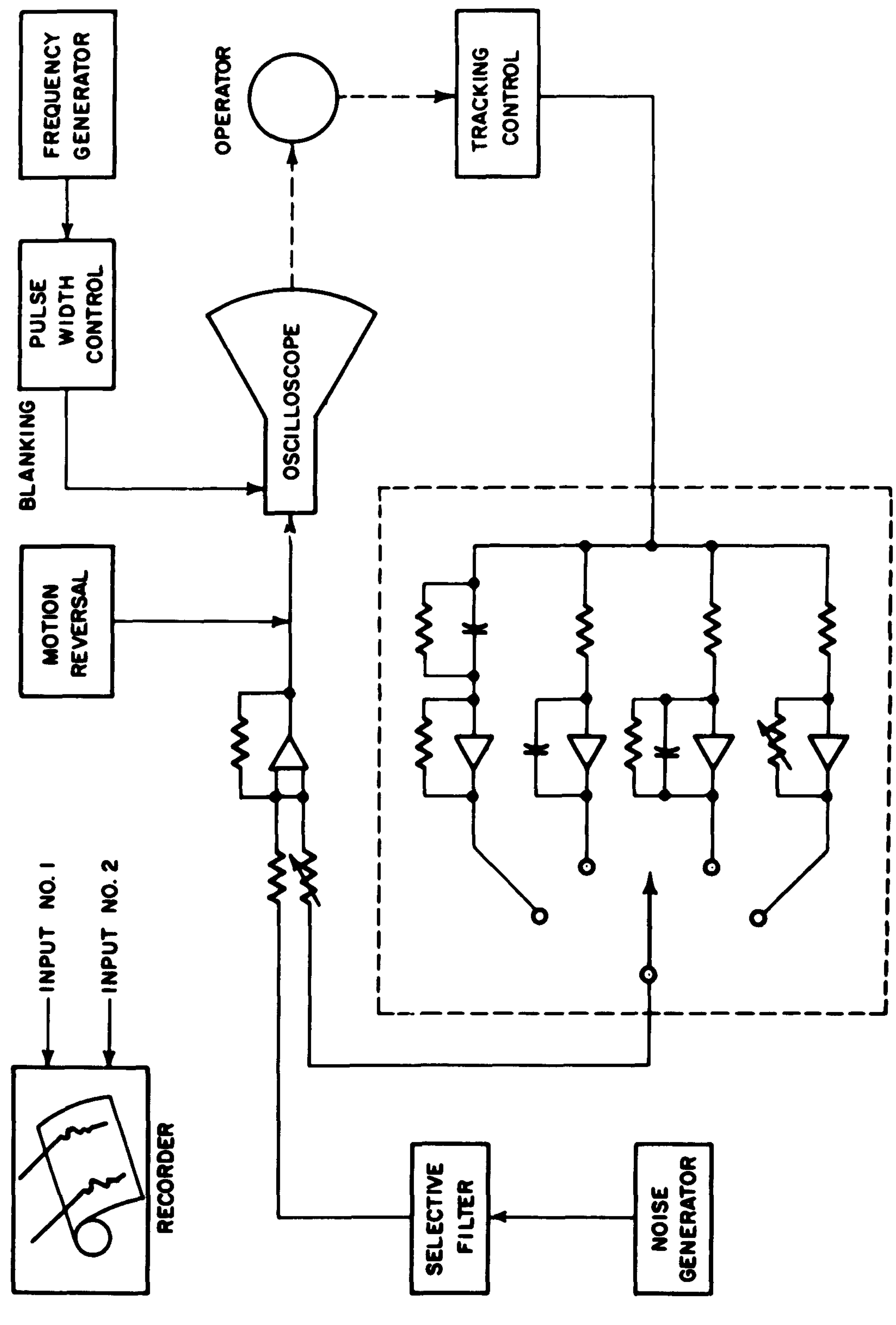

FIG. 3. SCHEMATIC DIAGRAM OF THE FIL ANALOG COMPUTER TRACKING DEVICE

Table 1A

Means and Standard Deviations of Time to Achieve Base Line*
Under Conditions of Change in Controlled Element Dynamics

Level of Change of Controlled Element Dynamics	Good Trackers				Poor Trackers			
	Training		No Training		Training		No Training	
	M	SD	M	SD	M	SD	M	SD
1	0.3110	0.6956	0.7475	0.7664	1.0486	0.7799	0.9153	0.6848
2	1.5413	0.4189	1.2271	0.6571	0.7803	0.8263	0.8331	0.8849
3	0.9301	0.9563	1.2213	0.7235	1.2514	0.6380	0.8203	0.8703

*Transformed scores

Table 2A

Means and Standard Deviations of Difference in RMS Error*
30 Seconds Before and After Change in Dynamics

Level of Change of Controlled Element Dynamics	Good Trackers				Poor Trackers			
	Training		No Training		Training		No Training	
	M	SD	M	SD	M	SD	M	SD
1	0.7120	0.0055	0.7136	0.0078	0.7187	0.0089	0.7162	0.0100
2	0.7134	0.0032	0.7133	0.0032	0.7122	0.0063	0.7197	0.0063
3	0.7131	0.0032	0.7045	0.0089	0.7143	0.0095	0.7152	0.0071

*Transformed Scores

Table 3A

Means and Standard Deviations of RMS Error at Each Intermittency Level*

% of Total Time Off	Good Trackers				Poor Trackers			
	Training		No Training		Training		No Training	
	M	SD	M	SD	M	SD	M	SD
95	1.09	0.03	1.09	0.05	1.13	0.07	1.11	0.03
85	1.00	0.02	1.01	0.02	1.01	0.03	1.04	0.02
60	0.96	0.02	0.93	0.01	0.96	0.01	0.98	0.01

Table 4A

Means and Standard Deviations of RMS Error for Each Level of Controlled Element Dynamics for the 30 Seconds Prior to Change

Level of Change of Controlled Element Dynamics	Level of Proficiency			
	Proficient		**Not Proficient**	
	M	SD	M	SD
1	0.31	0.05	0.38	0.06
2	0.31	0.04	0.41	0.07
3	0.32	0.06	0.40	0.05

Table 5A

Analysis of Variance for Dynamics: Mean RMS Error Over All Levels for the 30 Seconds Prior to Change

Source	df	MS	F
Between Subjects	23		
Proficiency (P)	1	0.1244	8.82**
Error	22	0.0141	
Within Subjects	48		
Level (L)	2	0.0018	1.50
L x P	2	0.0026	2.17
Error	44	0.0012	

**Significant at less than .01 level.

Table 6A

Means and Standard Deviations of RMS Error for Each Level of Controlled Element Dynamics for the 30 Seconds After Change

Level of Change of Controlled Element Dynamics	Level of Proficiency			
	Proficient		**Not Proficient**	
	M	SD	M	SD
1	0.35	0.06	0.44	0.08
2	0.32	0.05	0.42	0.08
3	0.34	0.06	0.42	0.05

Table 7A

Analysis of Variance for Dynamics: Mean RMS Error Over All Levels for the 30 Seconds After Change

Source	df	MS	F
Between Subjects	23		
Proficiency (P)	1	0.1511	10.72**
Error	22	0.0141	
Within Subjects	48		
Dynamics (D)	2	0.0032	1.03
P x D	2	0.0001	
Error	44	0.0031	

**Significant at less than .01 level.

GLOSSARY

Compensatory Tracking - The operator is presented with an input (display) consisting of an indicator showing the difference, or error, $\varepsilon(t)$, between the forcing function i(t), and the system output r(t). The operator's task is to minimize the error signal presented by trying to keep a dot superimposed on a stationary target.

RMS Error - Root Mean Square Error:

$$\varepsilon_{rms} = \sqrt{\frac{\int_0^T \varepsilon^2 dt}{T}}$$

Absolute Value of the Error - Error Voltage recorded without regard to sign.

radians/second - A unit for the measurement of frequency; 6.28 radians equal 1 cycle; 1 radian equals 57.3°.

Band Width - The width of the resonant curve, in frequency units, at the point at which the power in the circuit is one-half of the maximum power at resonance, expressed as a percentage of the resonant frequency.

Controlled Element - The dynamics of the type of element being controlled by the operator, such as an aircraft, automobile, etc., and the actual means of exerting control such as a stick or wheel with their associated restraints (springs, dampers, etc.).

Y_c - Controlled Element transfer function.

K_c - Gain of the Controlled Element.

s - Laplace operator.

Target Intermittency - Intermittent display of information. The picture painted on the PPI scope during one sweep decays before the next sweep.

Transfer Function - **The relationship between an input signal and the resulting output signal. For the purpose of this study, transfer function designates the relationship of a movement of the control stick to the resulting movement of the oscilloscope blip. Figure 4 shows the relationship of the movement of the control handle to the movement of the oscilloscope blip when the transfer function is a simple gain, $Y_c = 10$. Figure 5 presents the resulting response when Y_c is equal to $\frac{K}{s}$, K being equal to 1, 5, and 15, respectively.**

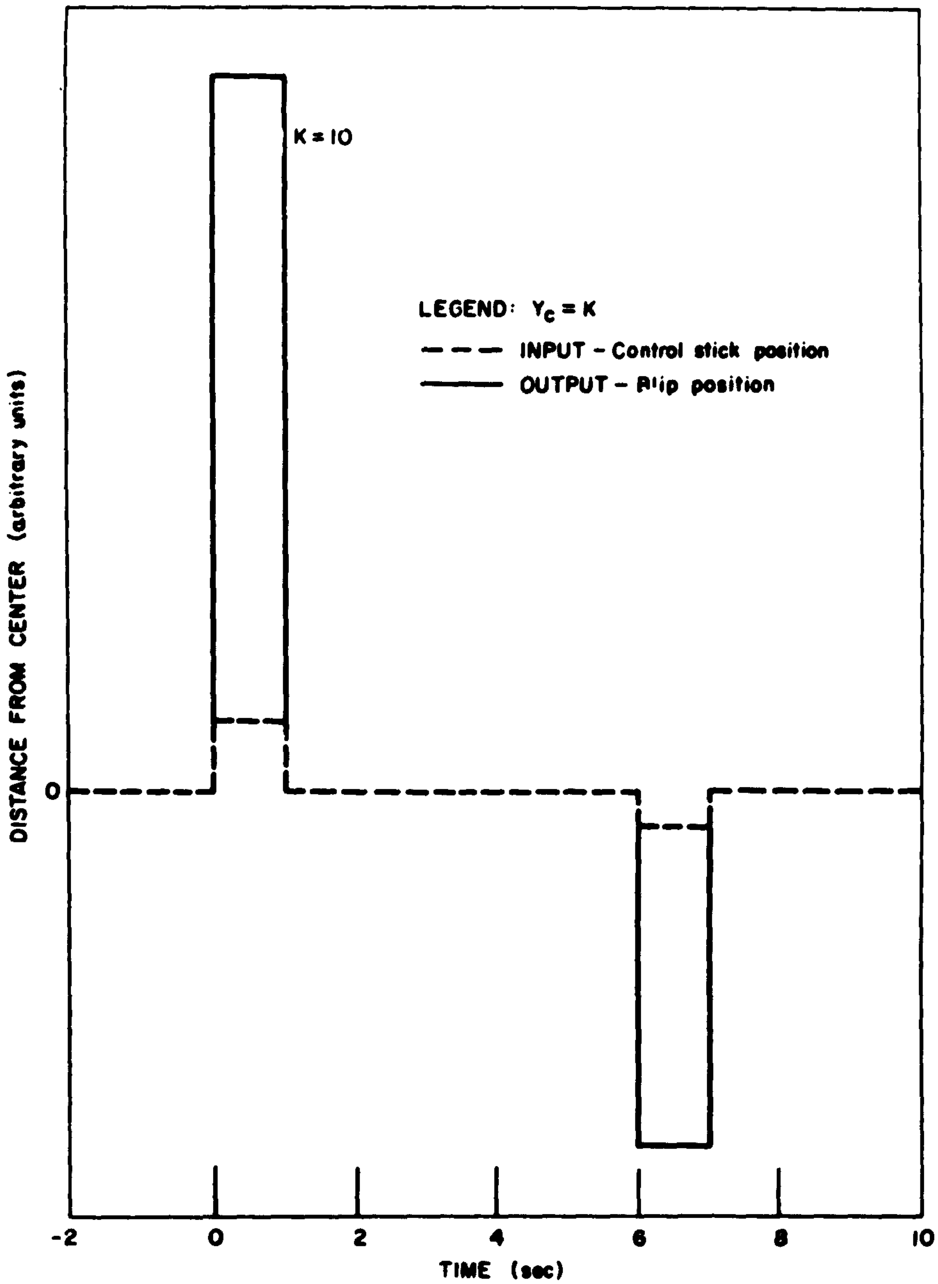

FIG.4- THE RELATIONSHIP OF CONTROL POSITION TO BLIP POSITION FOR THE FUNCTION $Y_c = K$

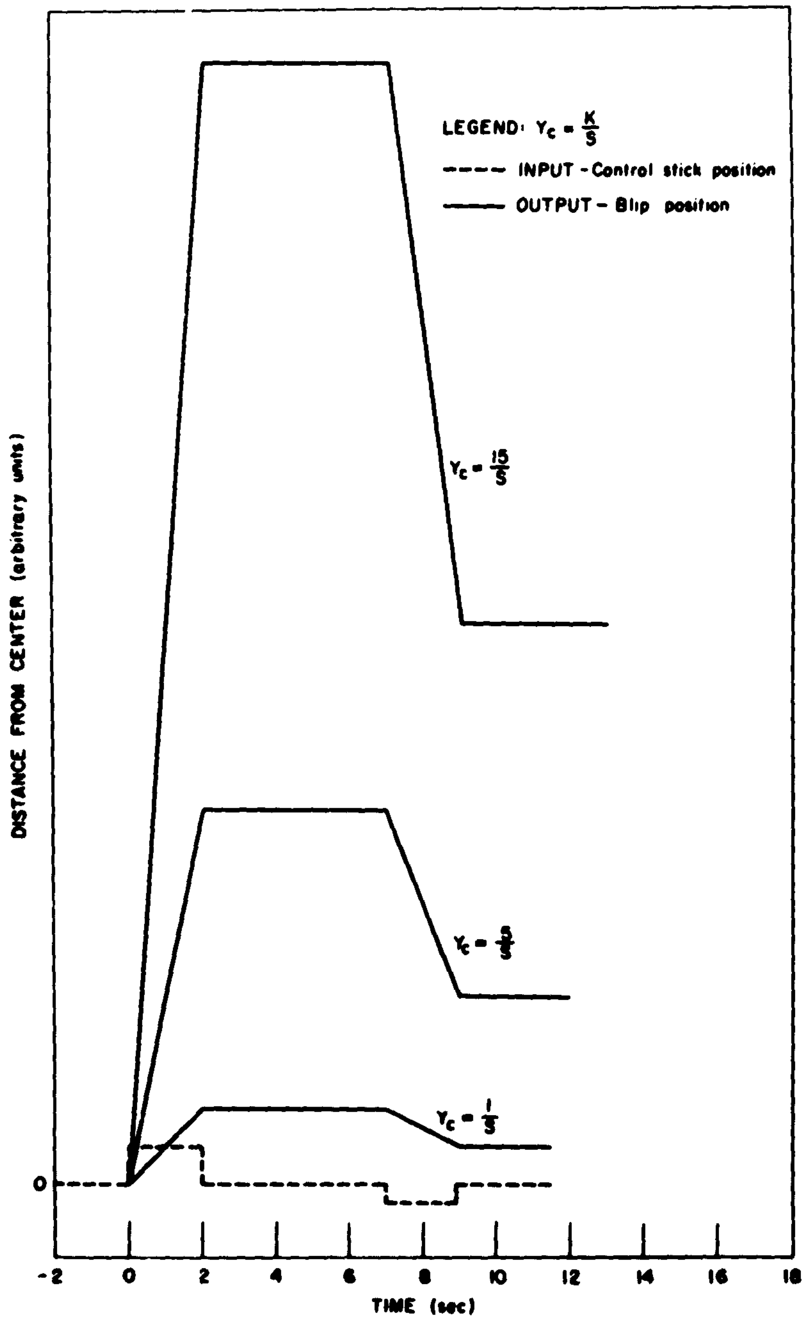

FIG. 5. THE RELATIONSHIP OF CONTROL POSITION TO BLIP POSITION FOR THE FUNCTION OF $Y_c = \frac{K}{S}$

(Forcing Function = 0)